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A review on global fuel economy standards, labels and technologies in the transportation sector

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ABSTRACT

Globally, the transportation sector is the second largest energy consuming sector after the industrial sector and accounts for 30% of the world's total delivered energy. In 2008 the transportation sector accounted for about 22% of total world CO_2 emissions. It is believed that this sector is currently responsible for nearly 60% of world oil demand. Within this sector, road vehicles dominate oil consumption and represents 81% of total transportation energy demand. The purpose of this paper is to highlight the possible opportunities to improve fuel economy and thus reduce global oil consumption and greenhouse gases. There are three measures that have been reviewed; passenger vehicle fuel economy and greenhouse gas emission standards, fuel economy labels and improvement in vehicle fuel efficiency by advanced technologies.

Fuel economy and greenhouse gas emission standards have proven to be one of the most effective tools in improving fuel economy. Japan and Europe lead the world with the most stringent passenger vehicle fuel economy standards. Labeling is another measure that could play an important role in consumers' vehicle purchasing decisions between similar vehicles. Labeling accompanied by standards of an appropriate type and level of stringency may yield synergistic results. In this review, several examples of fuel economy labels around the world have been presented such as in USA, United Kingdom, Canada, China and Australia. Finally, advanced technologies have been discussed. There are many technical opportunities to improve fuel efficiency and economy of motor vehicles. In this review, the possibilities of reducing vehicle power requirement, advanced engine and transmission technology and alternative power plants have been reviewed. It has been found that fuel economy standards, labels and technologies offer a massive potential of energy saving that can be achieved in this sector and thus the authors promoted adopting these measures in the transportation sector.

Contents

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1. Overview of transportation energy consumption in the world

Transportation sector has experienced steady growth in the past 30 years. It is believed that this sector is currently responsible for nearly 60% of total world oil demand and will be the strongest growing energy demand sector in the future. Between 2006 and 2030, around three quarters of the projected increase in oil demand is expected to come from transportation [1,2].

In the non-OECD countries, energy use for transportation increased by 4.38% in 2007 and 7.35% in 2008, before the impact of the 2008–2009 global economic recession resulted in a slowdown in transportation sector activity. Even in 2009, non-OECD transportation energy use grew by an estimated 2.93%, in part because many non-OECD countries (in particular, but not limited to, the oil-rich nations) provided fuel subsidies to their citizens. With robust economic recovery expected to continue in China, India, and other non-OECD nations, transportation energy use is expected to grow by an annual average rate of 3.16% from 2010 to 2035. In comparison with non-OECD economies, OECD energy use for transportation declined by an estimated 1.34% in 2008, followed by a further decrease estimated at 2.03% in 2009. Indications are that a return to growth in transportation energy use in OECD nations will not begin before late 2010, given the relatively slow recovery from the global recession anticipated for many of the OECD nations. Moreover, the United States and some of the other OECD countries have instituted a number of new policy measures to increase the fuel efficiency of their vehicle fleets, as well as fuel taxation regimes to encourage fuel conservation. Thus, OECD transportation energy use, is expected to grow by an annual average of 0.46% over the entire projection period between 2010 and 2035. In the long term, for non-OECD and OECD economies, energy demand for the transportation sector is projected to increase by an annual average of 1.8% over the entire period between 2010 and 2035 [3,4]. Fig. 1 shows total world, OECD and non-OECD transportation sector energy consumption in GJ between 2005 and 2035 [3].

Energy use in the transportation sector includes the energy consumed in moving people and goods by road, rail, air, marine, water and pipeline. The road transport includes light-duty vehicles such as automobiles, sport utility vehicles, minivans, small trucks, and motorbikes as well as medium and heavy-duty vehicles, such as large trucks used for moving freight and buses used for passenger travel. Road vehicles dominate global oil consumption and are one of the fastest growing energy. It represents 81% of transportation energy demand. In the USA, light duty passenger vehicles consume the highest amount of energy (57%) in 2007 as shown in Fig. 2 [1,5–8]. The number of cars on the road has increased from five million after the Second World War to nearly one billion today and is expected to reach two billion in the following 20 years. [9].

Globally, the transportation sector is the second largest energy consuming sector after the industrial sector and accounts for 30% of the world's total delivered energy. In USA, The transportation sector is the second largest energy consuming sector after the industrial sector. In 2009, it has accounted for 29% of total energy consumption as can be seen in Fig. 3 [10]. In Japan, transportation sector is the third largest energy consuming sector after industrial and commercial and residential sector and accounted to be 24.4% and 24.6% in 1996 and 2010 respectively as can be seen in Fig. 4 [11]. In China, the transportation sector consumes 7% of total energy consumption in 2000 as shown in Fig. 5. However, this share increased to 17% in 2003 [12,13]. In India, energy consumption in the transportation sector currently is believed to represent 15% of total energy consumption [14]. In Europe, transportation sector accounts for around a third of all final energy consumption [13,15,16].

Nomenclature

A	frontal area of the vehicle
ACEA	Association des Constructeurs Européens d'Automobiles
ADRs	Australian Design Rules
AMT	automated manual transmissions
ANFAVEA	Brazilian Automotive Industry Association
A/T	automatic transmission
BAS	belt driven alternator-starter
C_w	the air drag coefficient
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy program
CARB	California Air Resources Board
CONPET	The National Petroleum and Natural Gas Conservation Program
CVT	continuously variable transmission
CATARC	China Automotive Technology and Research Center
DEA	Danish Energy Agency
DOD	Displacement On Demand
DOE	Department Of Energy
EPA	Environmental Protection Agency
F_w	air resistance force
FCV	fuel cell vehicles
FE	fuel economy
FWD	front wheel drive
GDI	gasoline direct injection
HEV	hybrid electric vehicles
HSS	high-strength steel
IPENZ	The Institution of Professional Engineers New Zealand
JAMA	Japanese Automobile Manufacturers Association
KAMA	Korean Automobile Manufacturers Association
LCV	light commercial vehicles
LDT	light duty trucks
MCV	medium commercial vehicles
MIIT	China Ministry of Industry and Information Technology
M/T	manual transmission
MUVs	multi utility vehicles
MY	model year
NEDC	New European Driving Cycle
NHTSA	National Highway Traffic Safety Administration
Non-OECD countries	countries outside the Organization for Economic Cooperation and Development
OECD countries	Organization for Economic Cooperation and Development
OVC	overhead camshafts
PC	passenger car
PHEV	plug-in hybrids electric vehicles
SISS	smart idle stop system
SUVs	sport utility vehicles
V	vehicle speed
VTEC	variable valve timing and lift electronic control
VVT	variable valve timing

Greek letter

ρ	air density

Most of energy used in the transportation sector is in the form of liquid fuels [1,3,8,10,13,17]. The transportation sector share of world total liquids consumption increased from 50% in 2002 to 53% in 2007 and projected to reach 61% in 2035 accounting for 87% of the total increase in world liquids consumption. Fig. 6 shows total world liquids consumption, transportation liquids consumption and other sectors liquids consumption between 2007 and 2035 [1,8]. In China, it has been reported that transportation sector accounts for nearly 50% of total Chinese gasoline consumption [18]. Moreover, petroleum fuels represented 98%, 97% and 97% of total transportation fuel consumption in China in 2000, 2005 and 2010, respectively [12]. In 2008, the United States' transportation sector was responsible for 70% of the nation's petroleum consumption and 28% of total greenhouse gas emissions [10,19].

It is expected that about 4.1 billion metric tons of carbon dioxide will be released to the atmosphere from 2007 to 2020. It is estimated that another additional 8.6 billion metric tons carbon dioxide will be released to the atmosphere from 2020 to 2035. This is estimated to be about 43% increase for the aforementioned projected period. Fig. 7 shows the emission trends for OECD and non-OECD countries until 2035 [20].

In the transportation sector carbon dioxide (CO_2) represents the major GHG emission and accounts for 95%. An additional one percent of GHG emissions come from methane (CH_4) and nitrous oxides (N_2O). The leakage of hydro fluorocarbons (HFCs) from air conditioning systems is responsible for the remaining three percent of GHG emissions. Transportation sector also emits ozone, carbon monoxide (CO), and aerosols. These substances are not counted as greenhouse gases but are believed to have an indirect effect on global warming, although their impact has not been quantified with certainty [5].

Transportation sector accounted for about 23% and 22% of total world CO_2 emissions in 2007 and 2008, respectively [4,21]. Within this sector, road transport, accounting for 10% of global GHG emissions [22]. In 2004, According to the United Nations' Intergovernmental Panel on Climate Change (IPCC) the transportation sector was responsible for about 23% of total greenhouse gas emissions. Within this sector, passenger vehicles account for about 45% of this total [9]. In Europe, transportation sector accounts for more than a fifth of greenhouse gas emissions. It is also responsible for a large share of urban air pollution as well as noise nuisance. Moreover, between 1990 and 2001, emissions of greenhouse gases (GHGs) from transport (excluding international transport) increased by 20% [15,23]. In Australia, emissions from the transportation sector accounted for 13.7% of Australia's net emissions in 2006. Road transport was responsible for 87% of these emissions or in other words 12% of Australia's total emissions [24]. In USA, transportation sector is the second largest source of GHG emissions after the electric power sector as shown in Fig. 8. In 2008, almost 30% of total U.S. greenhouse gas emissions come from the transportation sector [5]. It is believed that USA alone contributes for about 25% of total global CO_2 emission [25]. In USA, carbon dioxide (CO_2) grew from 1586.9 million metric tons in 1990 to 1872.7 million metric tons in 2000 and reached a peak in 2007 with 2025.7 million metric. However, it decreased to 1930.1 million metric tons in 2008 at an average annual increase of 1.2% [26].

In USA, it is believed that 36% of transportation GHG emissions are produced from passenger cars (36%) followed by light trucks (19%), heavy trucks (16%), other (11%), aircraft (10%), marine (5%), rail (2%) and buses (1%) as shown in Fig. 9 [27].

In Japan, CO_2 emissions from the transport sector accounted for about 19% of total CO_2 emissions. About 90% of transport sector emissions are generated from road transport. While total worldwide CO_2 emissions from the transport sector have been increasing, CO_2 emissions from Japan's transport sector peaked in 2001 and have been on a downward trend ever since. The sector's total CO_2 emissions in 2001 amounted to 267 million tons, but by 2007 this decreased to 246 million tons, over-achieving the projected reduction target for 2010 (240–243 million tons). Japan, however, has been striving to further reduce these emissions [21,28]. In China, in 2005 road transport had the highest share on energy consumption

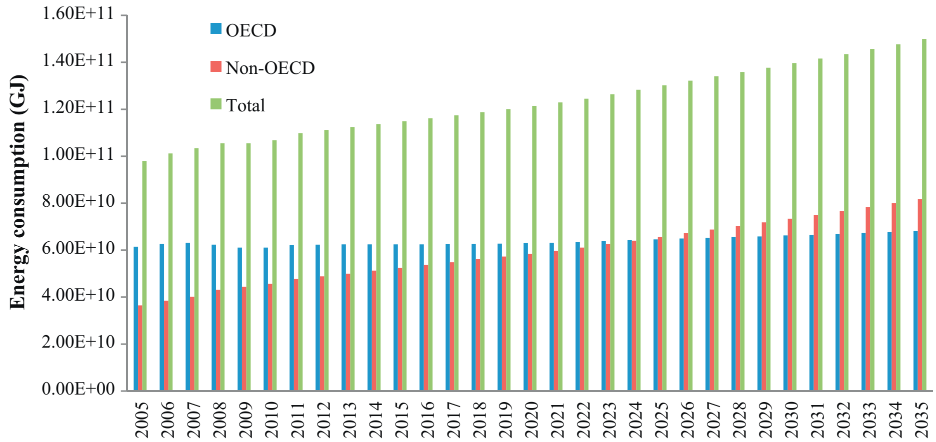

Fig. 1. Total world, OECD and non-OECD transportation sector energy consumption (GJ) between 2005 and 2035 [3].

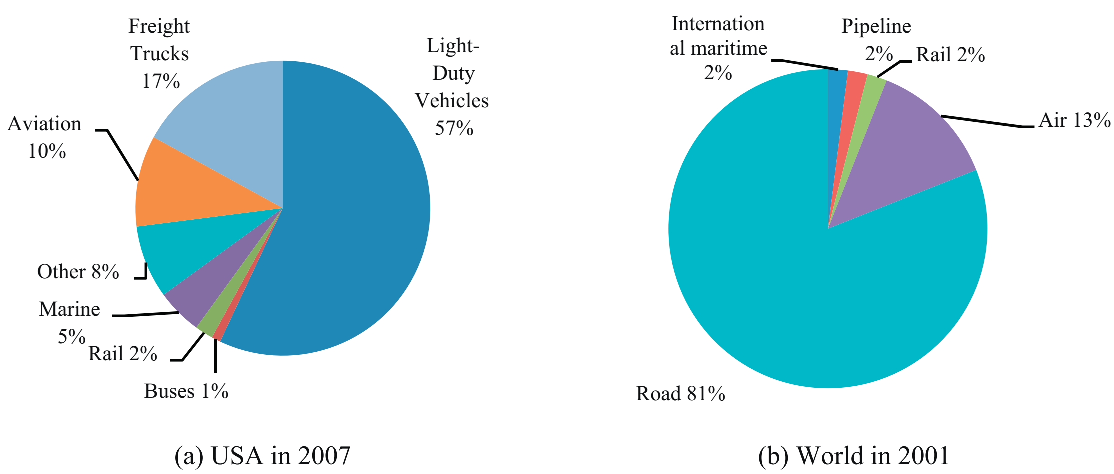

Fig. 2. Transportation energy use by mode [5,8].

and CO_2 emissions in transport (79%) followed by ship (8%), rail (7%) and air transport (6%) as shown in Fig. 10 [16].

2. Possibility of improving fuel economy and reduce carbon dioxide emissions in the transportation sector

There are many measures to improving fuel economy and reduce CO_2 emission of vehicles. Some of these measures include [13,17,19,25,29–31]:

- Fuel economy and greenhouse gas emission standards.
- Consumer information and labeling.
- Research and innovation for vehicle technology.
- De-emphasize increases in vehicle acceleration and horsepower performance.
- Use of alternative fuels such as advanced bio-fuels, hydrogen fuel cells and natural gas as alternatives to oil and alternative power plants such as hybrid vehicles (HEV) and fuel cell vehicles (FCV).
- Vehicle taxation and charges linked to emissions performance.
- Eco-driving.
- Reducing the distances travelled per vehicle.
- Consumer behavior and congestion avoidance.
- Investing in rail for freight and also passengers.
- Establishing green zones and green parking places for clean and fuel efficient cars such as in big cities.
- Offering incentives for low emission vehicles to encourage investment in appropriate emission reduction technologies.

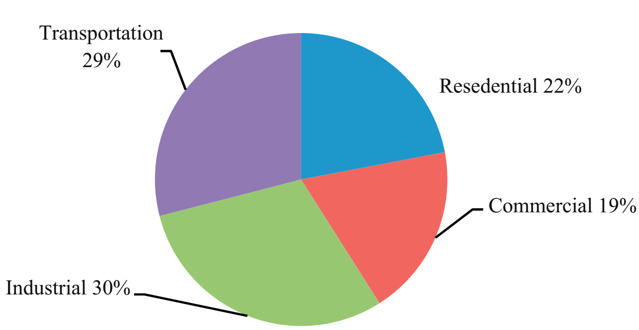

Fig. 3. End-use sector shares of total consumption in 2009 in USA [10].

3. Passenger vehicle fuel economy and greenhouse gas emission standards

In the transportation sector, automobile fuel economy standards have proven to be one of the most effective tools in controlling oil demand and greenhouse gas (GHG) emissions in many regions and countries around the world. Globally, there are nine major regions around the world that have implemented fuel economy and greenhouse gas (GHG) emission standards. These regions include: USA, European Union, Canada, Japan, China, Taiwan, South Korea and Australia [25,34].

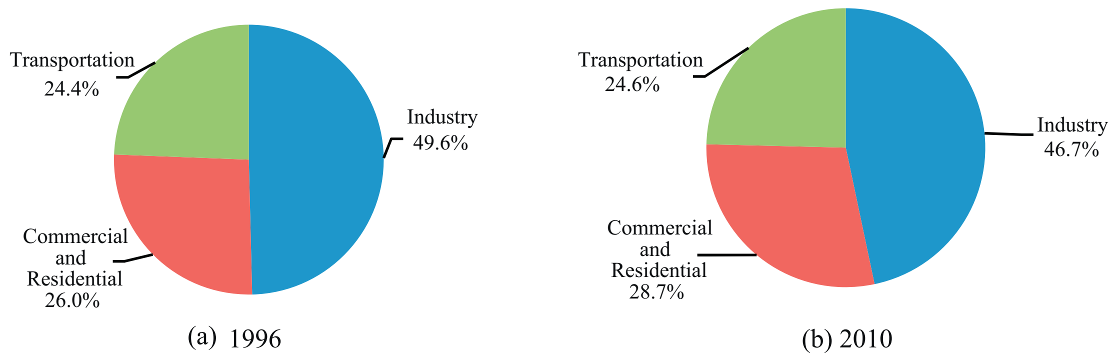

Fig. 4. Final energy demand in Japan in 1996 and 2010 [11].

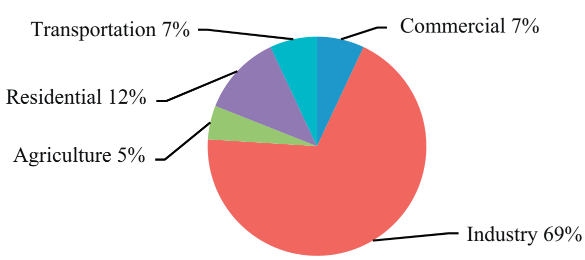

Fig. 5. Final energy demand in China in 2000 [12].

3.1. Fuel economy test methods

Fuel economy is measured based on a driving cycle for testing compliance of the vehicles with regulations. The driving cycle is designed to represent the actual driving pattern on road. The US, Europe and Japan have developed their own test procedures to measure vehicle emissions and fuel economy. Other countries have adopted these procedures fully or partially with modifications to suit their driving conditions. Table 1 shows a comparison of the US, Europe and Japan fuel economy test cycles. Table 2 gives a summary of fuel economy and GHG standards for vehicles around the world [2,18,22,25,29,30,33–36].

In 2004, an and Sauer developed a methodology to compare different fuel economy standards and greenhouse gas emissions around the world to better understand them. Their key findings are: Japan and Europe lead the world with the strictest regulations. Japanese standards are expected to lead to the lowest fleet average greenhouse gas emissions in the world (125 g CO_2/km by 2015). China is moving forward. However, U.S. automobile fuel

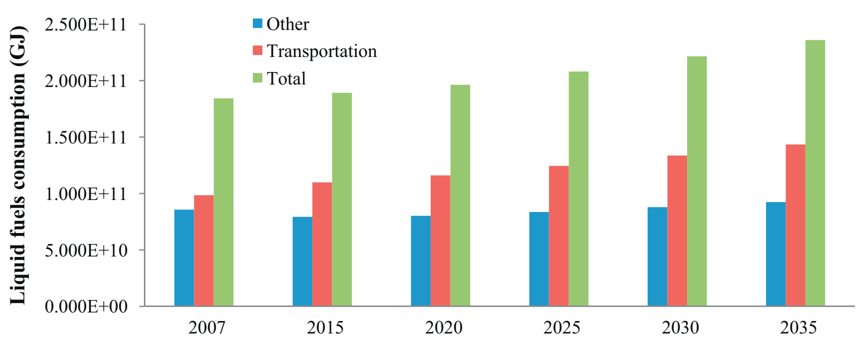

Fig. 6. Total world liquids consumption, transportation liquids consumption and other sectors liquids consumption between 2007 and 2035 (GJ) [1].

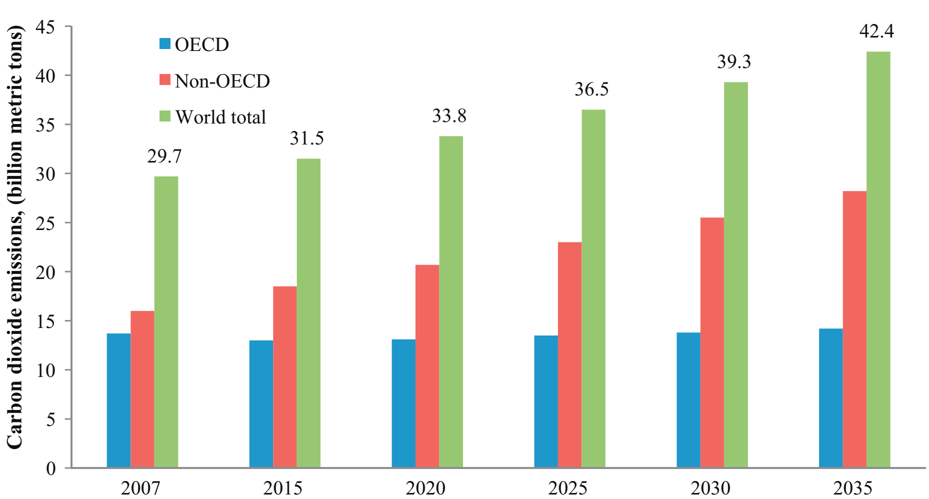

Fig. 7. Total world, OECD and non-OECD carbon dioxide emissions from 2007 to 2035 [3].

Table 1
Comparison of the US, Europe and Japan FE test cycles [29,35].

Test cycle	Duration, s	Length, km	Average speed, km/h	Maximum speed, km/h	Max. accn. m/s^2	%Idle time
NEDC	1180	11.01	NA	120	0.833	23.4
EPA highway	765	16.45	77.4	96.4	1.475	0
EPA city	1371	17.85	31.7	91.3	1.475	17.4
Japan 10–15	660	4.16	22.7	73.5	NA	31.4
JC08	1204	NA	24.5	81.6	1.70	NA

Table 2
Fuel economy and GHG standards for vehicles around the world [2,18,22,25,33,36].

Country/region	Type	Measure	Structure	Test method	Implementation
United States	Fuel	mpg	Cars and light trucks	U.S. CAFE	Mandatory
European Union	CO_2	g/km	Overall light-duty fleet	EU NEDC	Voluntary
Japan	Fuel	km/l	Weight-based	Japan 10–15	Mandatory
China	Fuel	l/100 km	Weight-based	EU NEDC	Mandatory
California	GHG	g/mile	Cars/LDT1 and LDT2	U.S. CAFE	Mandatory
Canada	Fuel	l/100 km	Cars and light trucks	U.S. CAFE	Voluntary
Australia	Fuel	l/100 km	Overall light-duty fleet	EU NEDC	Mandatory
Taiwan/South Korea	Fuel	km/l	Engine size	U.S. CAFE	Mandatory

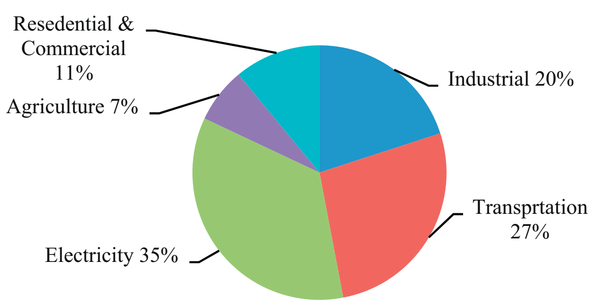

Fig. 8. U.S. greenhouse gas emissions by sector in 2008 [5].

economy standards lag behind them but could move ahead of Canada, Australia and South Korea by 2020. The summary of their findings is shown in Fig. 11 [22,25,33,35–37].

Many tax, fiscal, and technology approaches have been used in combination with fuel economy and GHG standards with varying degrees of success. Table 3 summarizes major approaches applied around the world for the purpose of promoting fuel-efficient automobiles.

3.2. Structures of fuel economy/GHG standards

The structures of fuel economy and GHG standards vary greatly among countries/regions. Some of these measures are as follow [2,30]:

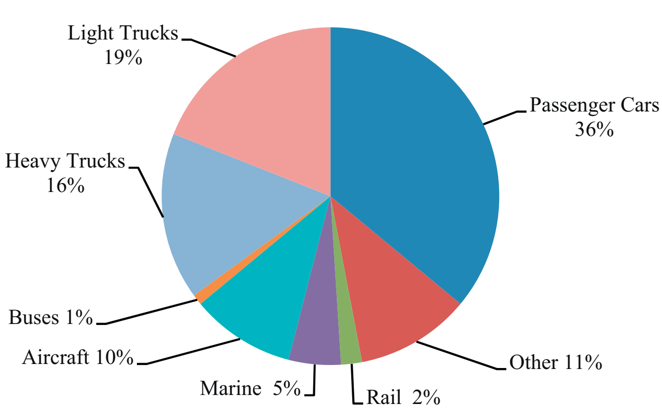

Fig. 9. Percentage of U.S. transportation GHG emissions by mode in 2000 [27].

- Fleet average target:
  - EU (CO_2 g/km)
  - Australia (l/100 km)
- Divided by vehicle categories:
  - US, Canada (mpg)—cars and LDTs,
  - California (CO_2, g/mile)—(PC/LDT1, LDT2)
- Based on vehicle/engine attributes:
  - Vehicle test weight bins:
    - Japan (km/l)—9 weight classes
    - China (l/100-km)—16 weight classes
  - Based on engine size:
    - South Korea (km/l)
  - Based on vehicle footprint:
    - Newly adopted in US and EU standards

3.3. Fuel economy standards and test methods around the world

3.3.1. USA

In the wake of the 1973 oil crisis, the U.S. Congress passed the Energy Policy and Conservation Act of 1975 with the goal of reducing the country's dependence on foreign oil. The act established the Corporate Average Fuel Economy program (CAFÉ) which is administered by National Highway Traffic Safety Administration (NHTSA). (CAFÉ) requires automobile manufacturers to meet a standard for the sales-weighted fuel economy of light duty passenger vehicles sold in the United States [33–35,38]. Each manufacturer receives a distinct average fuel economy that they must meet or exceed to avoid fines [39]. Light duty passenger vehicles (LDVs) include both passenger cars and light-duty trucks. The standards for light duty passenger vehicles were set starting from model year (MY) 1978/80 and are given in Table 4 [29].

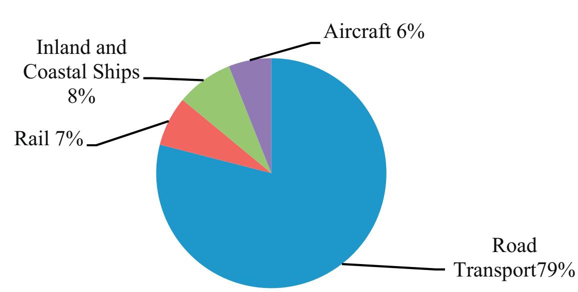

Fig. 10. Percentage of CO_2 emissions by mode in Chinese transportation sector in 2005 [16].

Table 3
Measures to promote fuel-efficient vehicles around the world [22,25,33,36].

Fuel efficiency approach	Measures/forms	Country/region
Fuel economy standards	Numeric standards in mpg, km/l or l/100 km	USA, Japan, Canada, Australia, China, Taiwan and South Korea
GHG emission standards	g/km or g/mile	European Union and California
High fuel taxes	Fuel taxes at least 50% greater than crude oil base price	European Union and Japan
Fiscal incentives	Tax relief based on engine size, efficiency and CO_2 emissions	European Union and Japan
R & D programs	Incentives for particular technologies and alternative fuels	USA, European Union and Japan
Economic penalties	Gas guzzler tax	USA
Technology mandates and targets	Sales requirement for ZEVs	California
Traffic control measures	Hybrid allowed in HOV lanes, ban on SUVs	Several USA states (hybrid HOV lanes), Paris (SUVs ban)

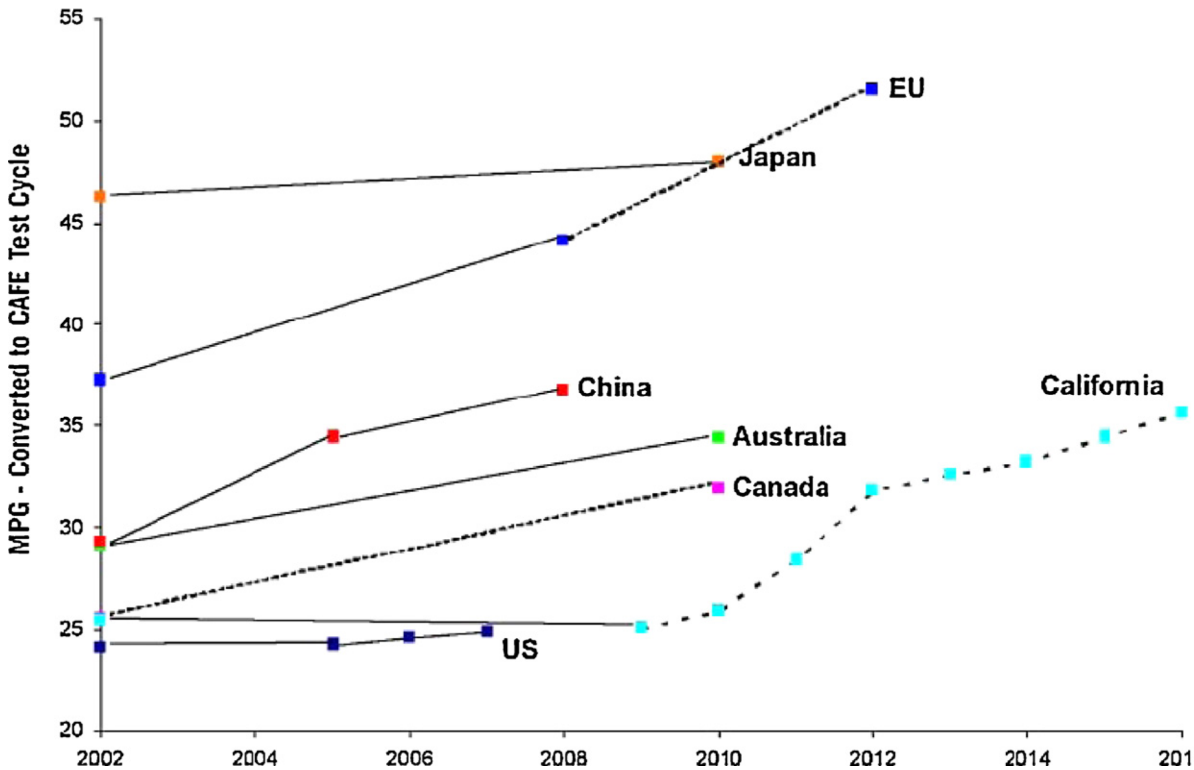

Fig. 11. Comparison of fuel economy standards mpg normalized by CAFÉ [22,25,33,36,37].

The standards for passenger cars remain unchanged since 1991 and stand at 27.5 mpg (11.7 km/l). The CAFE standards for light trucks have been revised upwards from 20.7 mpg in 1991 to 24.0 mpg to be achieved by the model year 2011 starting from the year 2007. The unreformed CAFE standards for light trucks are given in Table 5 [9,22,29,34,41].

Pursuant to the recent President's announcement of a National Fuel Efficiency Policy, the National Highway Traffic Safety Administration (NHTSA) and the EPA have promulgated nationally coordinated standards for tailpipe CO_2-equivalent emissions and fuel economy for both passenger cars and light-duty trucks. In the joint rulemaking, EPA is enacting CO_2-equivalent emissions

Table 4
Historical US Corporate Average Fuel Economy (CAFE) Standards, mpg [29,40].

Model year	Passenger cars	Light trucks combined	Light trucks (2WD)	Light trucks (4WD)
1978	18.0	–	–	–
1979	19.0	17.2	17.2	15.8
1980	20.0	14.0	16.0	14.0
1981	22.0	–	–	–
1982	24.0	17.5	18.0	16.0
1983	26.0	19.0	–	–
1984	27.0	20.0	20.3	18.5
1985	27.5	20.5	–	–
1986	26.0	20.5	20.5	19.5
1987	26.0	20.0	–	–
1988	26.0	20.5	21.0	19.5
1989	26.5	20.5	–	–
1990	27.5	20.0	20.5	19.0
1991	27.5	20.2	20.7	19.1
	Unrevised until 2008		Revised in 2005	

Table 5
Unreformed the US CAFE Standards for Light Trucks for MY 2007–2011 in mpg [29,30,41].

Model year	Fuel economy
2007	22.2
2008	22.5
2009	23.1
2010	23.5
2011	24.0

standards under the Clean Air Act (CAA), and NHTSA is enacting companion CAFÉ standards under the Energy Policy and Conservation Act [42].

The standards will affect model year (MY) 2012 vehicles, and compliance requirements will increase in stringency through MY 2016. NHTSA has estimated the impact of the new CAFE standards and has projected that the proposed fleet-wide standards for LDVs will increase fuel economy from 29.7 mpg in MY 2012 to 34.1 mpg in MY 2016 and 35 mpg in 2020, an average annual increase of 2.2%. EPA projects a fleet-wide reduction in CO_2-equivalent emissions from 295 g/mile for MY 2012 to 250 g/mile for MY 2016 (Table 6) [39,42].

The fuel standards use an attribute-based methodology to determine the minimum fuel economy requirements and CO_2-equivalent emissions standards for vehicles based on footprint, defined as the wheelbase (the distance from the center of the front axle to the center of the rear axle) times the average track width (the distance between the center lines of the tires) when the tires are mounted on rims with zero offset and wheelbase is the longitudinal distance between front and rear wheel centerlines. All of these distances are measured in square feet. In case of multiple rear axles, wheelbase is measured to the midpoint of the centerlines of the front wheels and wheels on the rearmost axle. Figs. 12 and 13 show projected average fleet-wide fuel economy and CO_2 equivalent emissions compliance levels for passenger cars and light trucks, model year 2016 [6,29,42,43].

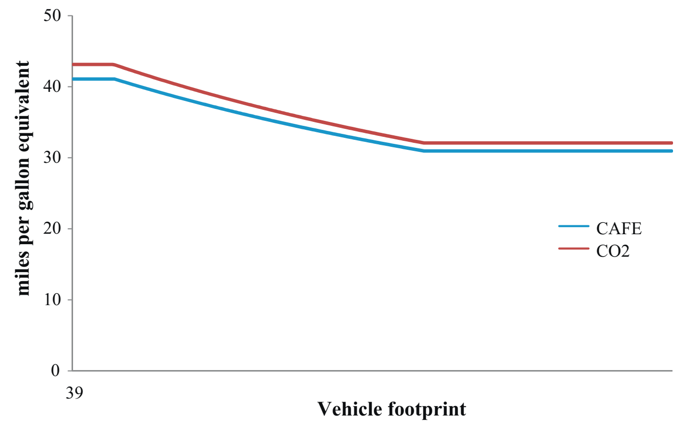

Fig. 12. Projected average fleet-wide fuel economy and CO_2-equivalent emissions compliance levels for passenger cars, model year 2016 (miles/gallon equivalent) [42].

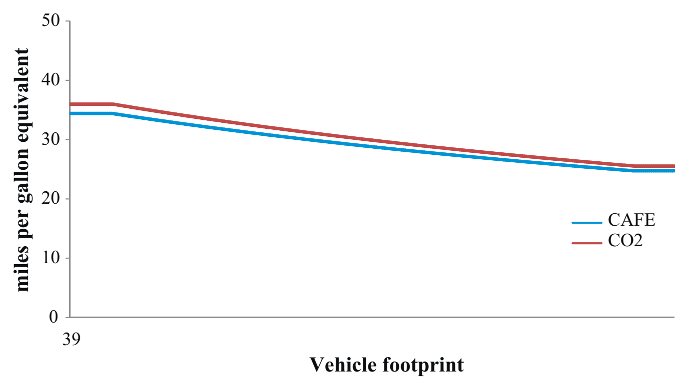

Fig. 13. Projected average fleet-wide fuel economy and CO_2-equivalent emissions compliance levels for light trucks, model year 2016 (miles/gallon equivalent) [42].

3.3.2. California

In 2002, California enacted legislation directing the California Air Resources Board (CARB). This legislation requires motor vehicles to achieve the maximum feasible and cost-effective reduction of GHGs. In September 2004, the draft regulations were approved by the CARB and the standard took effect with the 2009 model year passenger vehicles. CARB has proposed near-term standards to be phased in from 2009 through 2012, and mid-term standards to be phased in from 2013 through 2016. The standards become more stringent annually, so that by 2016, the new vehicle fleet average standard would be 30% below the 2009 level. These standards have been divided by CARB into two categories. The first category is set for the passenger car/light-duty truck 1 (PC/LDT1), which includes all passenger cars regardless of weight and light-duty trucks weighing less than 3750 lbs. The second category is set for light-duty truck 2 (LDT2) for light trucks weighing between 3751 lbs and 8500 lbs this category also includes medium-duty passenger vehicles (MDPVs) vehicles weighing 8500–10,000 lbs. Table 7 shows a summary of California Air Resources Board approved standards [33,34,44].

Table 6
Estimated average fleet-wide fuel economy and CO_2 equivalent emissions compliance levels, model years 2012–2016 [35,42].

Model year	Passenger car	Light truck	Combined
NHTSA CADE standard (miles/gallon)			
2012	33.3	25.4	29.7
2013	34.2	26.0	30.5
2014	34.9	26.6	31.3
2015	36.2	27.5	32.6
2016	37.5	28.8	34.1
EPA CO_2 equivalent emissions standard (g/mile)			
2012	263	346	295
2013	256	337	286
2014	247	326	276
2015	236	312	263
2016	225	298	250

3.3.3. Japan

In 1999, the Japanese fuel economy standards were established for gasoline and diesel powered light-duty passenger and commercial vehicles. Standards are determined based on the performance of the vehicles whose performance is the best based on the "Top Runner" method. These standards are set based on weight class.

Table 7
California Air Resources Board approved standards [33].

Time frame	Year	GHG emission standard (CO_2 in g/mile)		CAFE equivalent standard (mpg)	
		PC/LDT_1	LDT_2	PC/LDT_1	LDT_2
Near-term	2009	323	439	27.6	20.3
	2010	301	420	29.6	21.2
	2011	267	390	33.3	22.8
	2012	233	361	38.2	24.7
Medium-term	2013	227	355	39.2	25.1
	2014	222	350	40.1	25.4
	2015	213	341	41.8	26.1
	2016	205	332	43.4	26.8

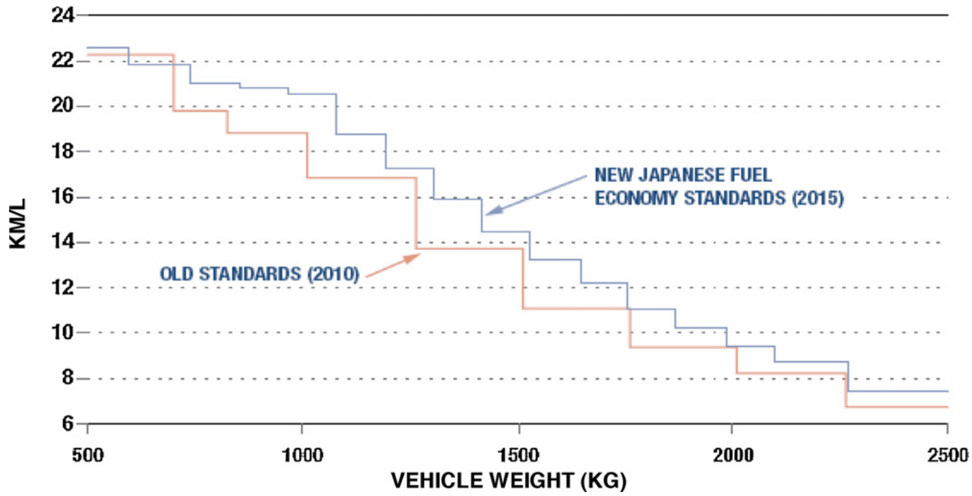

Fig. 14. The new Japanese vehicle fuel economy standards effective from the model year 2015 [28,29,34,35].

Table 8
Japanese Fuel Economy Standards for passenger cars (km/l) [29,33,45].

Vehicle mass, kg	Gasoline cars (2010)	Diesel cars (2005)	LPG (2010)
≤702	21.2	18.9	15.9
703–827	18.8	18.9	14.1
828–1015	17.9	18.9	13.5
1016–1265	16.0	16.2	12.0
1266–1515	13.0	13.2	9.8
1516–1765	10.5	11.9	7.9
1766–2015	8.9	10.8	6.7
2016–2265	7.8	9.8	5.9
≥2266	6.4	8.7	4.8

Table 9
Japan gasoline LCV and MCV year-2010 fuel economy standards (km/l) [29].

Vehicle mass, kg	Light commercial vehicles				Medium commercial vehicles	
	Car derivative		Others		Car derivative	
	A/T	M/T	A/T	M/T	A/T	M/T
≤702	18.9	20.2	16.2	17.0	–	–
703–827	16.5	18.0	15.5	16.7	–	–
828–1015	–	–	14.9	15.5	–	–
1016–1265	–	–	14.9	17.8	12.5	14.5
1266–1515	–	–	13.8	15.7	11.2	12.3
≥1516	–	–	–	–	10.3	10.7

The regulations were revised again in 2001 to allow automakers to accumulate credits in one weight class and use them in another weight class. The standards applicable for the passenger cars, light commercial vehicles and medium commercial vehicles are given in Tables 8–10. The targets for gasoline vehicles are to be met by 2010, while 2005 is the target year for diesel vehicles. In Japan, the majority of gasoline passenger vehicles sold in 2002 already met or exceeded the 2010 standards. Therefore, the fuel economy targets were revised again in December 2006 upwards to be effective from the year 2015, even before the gasoline vehicle FE standards were yet to be implemented from the year 2010. The number of weight categories was increased from 9 to 16. These new standards notified for implementation from the model year 2015, are shown in Fig. 14. The new standards are projected to improve the fleet average fuel economy of new passenger vehicles from 13.6 km/l in 2004 to 16.8 km/l in 2015 giving an improvement of 24% [6,9,22,29,33,35,44,45]. JAMA (Japanese Automobile Manufacturers Association) have a goal to achieve CO_2 emission reductions of 25% in 2009 [36].

Table 10
Japan diesel LCV and MCVs fuel economy standards (year 2005) (km/l) [29].

Vehicle mass, kg	MCV (A/T)	MCV (M/T)	LCV (A/T)	LCV (M/T)
≤1265	12.6	14.6		
1266–1515	12.3	14.1	15.1	17.7
1516–12765	10.8	12.5	For all masses	Or all masses
≥1766	9.9	12.5		

3.3.4. European Union

During 1990s, the European Union and the associations of vehicle manufacturers association, Association des Constructeurs Européens d'Automobiles (ACEA) set voluntary agreements to reduce emissions of carbon dioxide (CO_2) from vehicles. The year 1995 was taken as the base year and 25% reduction was proposed to be achieved in 2008. In June 2007, the Council of Environment Ministers formally adopted a resolution to make the 2012 targets mandatory. The EU target of 120 g CO_2/km (46 mpg) by 2012 would be met through an "integrated approach" between the EU and the association of car manufacturers. In this approach, car manufacturers would achieve 130 g/km (42 mpg) through technical improvements in vehicle and engine and the remaining reduction of 10 g/km from other measures such as efficient tires and air conditioners, improvements in light-commercial vehicles and increased use of bio-fuels. By 2015 all new cars must meet this standard. In Europe, the long-term goal for the fleet average of new cars is 95 g CO_2/km (or 58 mpg) by 2020 with a review in 2013. Table 11 shows a summary of these targets between 1995 and 2020 [9,22,25,29,30,33,35,41,44,46,47].

The agreement covers all vehicles produced or imported into the European Union by member companies (BMW, Daimler

Table 11
Fleet averaged greenhouse gas, CO_2 emission standards in Europe (g/km) [29,33,35,41,44,48].

Year	New car fleet average	Approx. equivalent FE[a], km/l of gasoline
1995	185 (base value)	12.6
2003	165 (achieved)	14.1
2004	161	–
2008 (target)	140	16.6
2012 (target)	120[b]	19.4
2020	95	–

[a] FE in km/l of gasoline = 2325/CO_2 g/km.
[b] 130 g/km through vehicle technology and further 10 g/km reduction via bio-fuels.

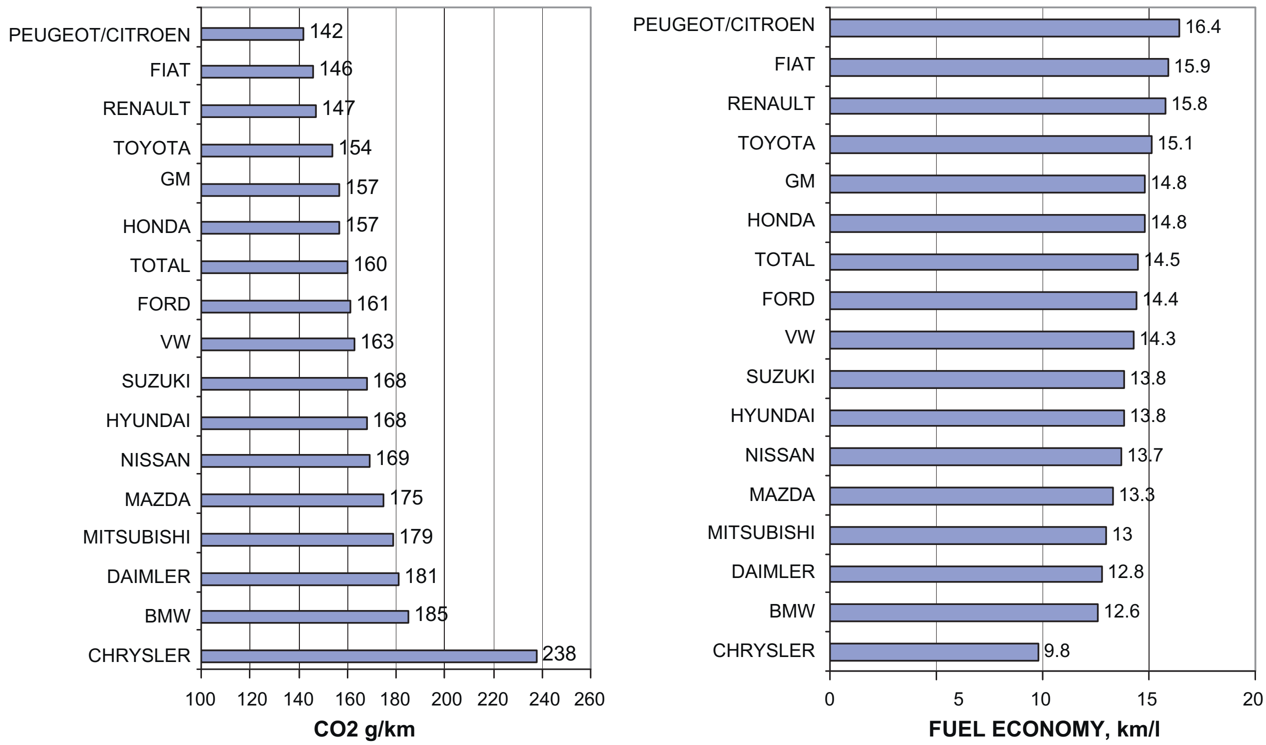

Fig. 15. Fuel economy range of cars sold in Europe in 2006 [29,34].

Chrysler, Fiat, Ford, GM, Porsche, PSA Peugeot Citroën, Renault, and VW Group). As part of the agreement with ACEA, the European Commission initiated similar negotiations in 1998 with the Korean and Japanese manufacturers. The Korean Automobile Manufacturers Association (KAMA) includes Daewoo, Hyundai, Kia, and Ssangyong; the Japanese Automobile Manufacturers Association (JAMA) includes Daihatsu, Honda, Isuzu, Mazda, Mitsubishi, Nissan, Subaru, Suzuki, and Toyota. In 2006, car sellers fleet average CO_2 emissions in EU ranged from 142 to 238 g/km or equivalent to 9.8 to 16.4 km/l (Fig. 15). The data showed that several European vehicle manufacturers like Peugeot/Citroen, Fiat, Renault, and Volkswagen are currently manufacturing cars with lower CO_2 emissions than Asian manufacturers selling cars in Europe (Fig. 16) [29,33,41].

3.3.5. China

China became the largest auto producer and market in 2009. However, China's oil supply depends increasingly on import from other countries [18]. Therefore, China has set a vehicle fuel economy goal of 35.8 mpg by 2009 [9]. Recently, China has approved new regulations of fuel economy standards for its passenger vehicle fleet to control the country's rapidly growing vehicle market. These standards are mainly intended to alleviate China's increasing reliance on foreign oil, but another objective is to promote foreign automakers to bring more fuel efficient vehicle technologies to the Chinese market. The new standards will be implemented in two phases: Phase 1 will take effect on July 1, 2005, for new vehicle models, and on July 1, 2006, for continued vehicle models. Phase 2 will take effect on January 1, 2008, for new models and on January 1, 2009, for continued vehicle models. One distinctive feature of

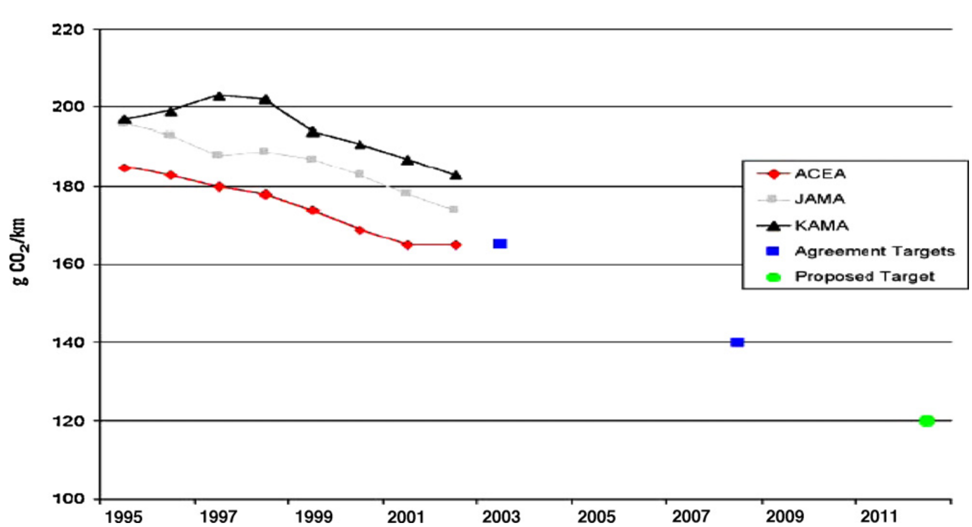

Fig. 16. Progress and targets under the ACEA agreement [33].

Table 12
Maximum limits for fuel consumption (l/100-km) and minimum CAFE-equivalent mpg limits, for passenger vehicles in China (excluding Taiwan) [32,33].

Weight, lbs	Maximum fuel consumption limits based on NEDEC cycle (l/100 km)				Minimum fuel economy limits based on U.S CAFE—equivalent, mpg			
	Phase 1 (2005)		Phase 2 (2008)		Phase 1 (2005)		Phase 2 (2008)	
	Manual	Auto/SUV	Manual	Auto/SUV	Manual	Auto/SUV	Manual	Auto/SUV
≤1667	7.2	7.6	6.2	6.6	36.9	35.0	42.9	40.3
≤1922	7.2	7.6	6.5	6.9	36.9	35.0	40.9	38.5
≤2178	7.7	8.2	7.0	7.4	34.5	32.4	38.0	25.9
≤2422	8.3	8.8	7.5	8.0	32.0	30.2	35.4	33.2
≤2678	8.9	9.4	8.1	8.6	29.9	28.3	32.8	30.9
≤2933	9.5	10.1	8.6	9.1	28.0	26.3	30.9	29.2
≤3178	10.1	10.7	9.2	9.8	26.3	24.8	28.9	27.1
≤3422	10.7	11.3	9.7	10.3	24.8	23.5	27.4	25.8
≤3689	11.3	12.0	10.2	10.8	23.5	22.2	26.1	24.6
≤3933	11.9	12.6	10.7	11.3	22.3	21.1	24.8	23.5
≤4178	12.4	13.1	11.1	11.8	21.4	20.3	23.9	22.5
≤4444	12.8	13.6	11.5	12.2	20.8	19.5	23.1	21.8
≤4689	13.2	14.0	11.9	12.6	20.1	19.0	22.3	21.1
≤5066	13.7	14.5	12.3	13.0	19.4	18.3	21.6	20.4
≤5578	14.6	15.5	13.1	13.9	18.2	17.1	20.3	19.1
≥5578	15.5	16.4	13.9	14.7	17.1	16.2	19.1	18.1

the Chinese standards is that they set up maximum allowable fuel consumption limits by weight category rather than being based on fleet average. Each vehicle sold in China will be required to meet the standard for its weight class. The standards will be classified into 16 weight classes, ranging from vehicles weighing less than 750 kg (approximately 1500 lbs) to vehicles weighing more than 2500 kg (approximately 5500 lbs). Table 12 shows maximum limits for fuel consumption (l/100 km) and minimum CAFÉ equivalent mpg limits for passenger vehicles in China (excluding Taiwan) [13,18,32–34,49].

The current level of fuel economy standards of the Chinese vehicle is not well recognized as the data have not become available in public. Therefore, the relative effect of these standards is not well understood. However, the standards were designed to be "bottom heavy" meaning that they become relatively more stringent in the heavier vehicle classes than in the lighter weight classes. This will help to create incentives for manufacturers to produce lighter vehicles for the Chinese market [32,33].

4. Passenger fuel economy labels

Fuel economy labels can play an important role in vehicle purchasing decisions between similar vehicles that have different fuel efficiency ratings. However, they have not seemed to have had a big impact thus far. Governments have been asking manufacturers to introduce labeling schemes with the hope that they will lead to fuel savings. Labeling accompanied by standards of an appropriate type and level of stringency may yield synergistic results. Such information should include the expected fuel efficiency range for most drivers, estimated annual fuel cost and a performance comparison with similar vehicles. Globally, there are various labeling schemes have been introduced. Some of these schemed are highlighted in the following section [6]. Appendix A shows a selection of fuel economy labels in different countries around the world [6,31,34,49–57].

4.1. Requirement of car labels

A label for new passenger cars, aimed to inform consumers about the fuel economy of different passenger cars, should be [57]:

(i) Simple and easily understood by purchasers.
(ii) Insensitive for manipulation: it should not be possible to change the classification of a model by simple manipulation by the manufacturer.
(iii) Durable in order to make sure that current as well as future cars are classified correctly.
(iv) Workable: standardized fuel consumption data have to be based on available vehicle characteristics such as mass, external dimensions, specific engine power or specific carrying capacity.
(v) Conspicuous and well known in order to achieve purchaser's attention.
(vi) Adjustable to technological developments in fuel economy.
(vii) Accepted and supported by consumers, authorities, automobile and consumer associations and if feasible, by the car industry and car dealers.

4.2. Fuel economy labels around the world

4.2.1. United States

In the United States, a fuel economy guide is published annually by the DOE (Department of Energy). This guide explains the information given on a fuel economy label which must be affixed to the window of all new light-duty vehicles in the showroom. This allows customers to compare the fuel economy of cars of about the same size. This information is also given on the label together with estimated vehicle's fuel efficiency for "city" and "highway" per unit distance of travel (in l/100 km or gallons/100 miles). The label also contains the best and worst fuel economies of vehicles in this class. This gives consumers an idea of the fuel economy for a specific model to compare with other cars [6,19].

4.2.2. Canada

In Canada, there is an existing agreement between car manufacturers to reduce fuel consumption through voluntary fuel economy labels and guidelines for all new cars. The label should be affixed by manufacturers or importers. Information within these labels include type, number of cylinders, fuel metering system, transmission type, fuel type, fuel consumption for "city" and "highway" ['l/100 km' and 'miles/gallon'] and advises that actual consumption may vary from the given values. However these labels do not have direct comparison with other cars [6,50].

4.2.3. United Kingdom

Over the last few decades, a various range of labeling schemes has been introduced in UK to inform consumers about environmentally or socially related product attributes. A fuel economy label must be affixed to new passenger cars for sale in car dealer's showrooms. Information on the label includes model name and fuel

consumption for urban, extra urban and combined test cycle. Format and size are set and there is a note on the label stating the influence of driving behavior, level of maintenance, road and traffic conditions on fuel consumption. Authorities are permitted to publish fuel consumption data for all models on the market and this information must be made available to consumers on request. The label does not contain a comparison of the specific model, as against cars of the same class or the entire fleet of new passenger cars [6].

4.2.4. The Netherlands

The Ministry of Public Housing, Spatial Planning and Environment has proposed a labeling system for passenger cars. This labeling system has been proposed as a complementary measure within the framework of the Community strategy to reduce CO_2 emissions from passenger cars. The objectives are to provide information to consumers and to enhance the effectiveness of fiscal measures. The proposal was implemented in 2000. The label compares relative fuel economy, i.e. the measure, against which a car uses more or less fuel than the average of all cars with the same length $\times$ width in m^2. The layout of the label is derived from the EU Energy Label for electric household appliances [6]. The fuel economy label provides the following information:

- Passenger car model.
- Year of application of the label.
- Absolute fuel consumption [l/100 km, km/l].
- CO_2 emission.
- Comparison of relative fuel economy [%].
- Fuel costs for 50,000 km.

4.2.5. Sweden

Since 1978, Sweden started a labeling system for new passenger cars as part of the governmental information guidelines on specific fuel consumption, carbon dioxide emissions and environmental categories of new passenger cars. A new label has been used since 1 January 1997, which includes the following information [6,52]:

- Model.
- Manufacturer.
- Fuel consumption [l/100 km].
- CO_2 emissions [g/km].
- Environmental category of the car from 1 (best) to 3 (worst), based on how clean its emissions.
- Purchasers are advised to request further information in the form of brochures and posters from the car dealer.

The car label is accompanied by:

- Posters in dealer's showrooms listing fuel consumption and CO_2 emissions of all the models available from the dealer to allow a comparison.
- Booklet listing all car models and all makes (fuel economy guide).

4.2.6. Switzerland

Within the Swiss energy conservation program "Energy 2000", a "Fuel Saving Label" has been introduced. This marketing instrument aimed to reduce specific fuel consumption of new passenger cars by 15% in 2001, compared to 1996, as required by law. The car industry, importers, dealers and automobile clubs have taken part in the decision-making process. Originally the label is valid for one year and all types or models of passenger cars meeting certain criteria will be labeled. The measuring scale would have been specific fuel consumption in l/100 km normalized to the weight of the car [6,53].

4.2.7. China

To promote consumer awareness of energy consumption, China implemented first-ever mandatory fuel economy labeling for passenger in July 2008. The label, to be placed on the vehicle's window, displays fuel consumption estimates for highway, city, and overall average driving patterns [13,58]. The label should contain the following information [18,49,59]:

- Production enterprise.
- Vehicle type.
- Engine type, emission, rated power, of which the unit for the engine emission is expressed in ml and the unit for the rated power is expressed in kW.
- Fuel type, such as petrol, or diesel oil.
- Transmission type, such as hand operated, automatic, or MT, AT, AMT, CVT.
- Driving mode, such as front-wheel drive, rear-wheel drive and four-wheel drive.
- Gross vehicle mass, maximum design total mass, unit is expressed in kg.
- Town area, suburban area and comprehensive fuel consumption, unit is l/100 km.
- Applicable standards for fuel consumption limitation, specific implementation date of fuel.
- Consumption limit at each phase and corresponding fuel consumption limit, the unit of which is expressed as l/100 km.
- Caption of the differences between the fuel consumption on the label and actual fuel consumption.

4.2.8. Brazil

In 2008, the Brazilian government introduced a vehicle labeling program that was aimed at increasing energy efficiency for the new light duty vehicle fleet. In this labeling program, participating manufacturers must reveal fuel consumption data for at least 50% of their models which have sales of more than 2.000 units per year. However, the display of fuel economy labels in showrooms is voluntary. More recently, in early 2009 a major breakthrough was achieved when a joint group of governmental bodies and ANFAVEA (Brazilian Automotive Industry Association) agreed to establish standard procedures for measurement of light cars energy efficiency. In May 2009, CONPET (The National Petroleum and Natural Gas Conservation Program) launched a voluntary energy efficiency label for the sale of new light vehicles in the Brazilian market, which has already been adopted by some leading car manufacturers. Under this program, vehicles are classified in five classes of energy consumption (A through E), where class "A" is the most efficient. The vehicles are grouped in eight categories, four of which are based on end use: sports, off-road, light commercial and cargo vehicle (based on passenger car); and four are based on vehicle size: subcompact, compact, mid size and large [54,60,61].

4.2.9. Australia

In Australia, all new light vehicles sold are required to display a fuel consumption label on the front windscreen. This includes all passenger cars, four wheel drives and light commercial vehicles up to 3.5 tons gross vehicle mass. Design and construction standards for new and imported vehicles are set out in the Australian Design Rules (ADRs), which are mandatory national standards under the Motor Vehicle Standards Act 1989. The label indicates the vehicle's fuel consumption in liters of fuel per 100 km (l/100 km) and its emissions of carbon dioxide (CO_2) in grams per kilometer (g/km). The label is designed to help Australian motorists make informed choices about the environmental impact of their new car and the cost of running their vehicle. Raising awareness about the relative greenhouse impacts of different technologies and fuel types, and encouraging consumers to purchase vehicles with better fuel

economy, can help reduce Australia's greenhouse gas emissions. Since April 2009, a new improved fuel consumption label has been required on showroom vehicles. The new label displays three fuel consumption numbers combined, urban and extra-urban as well as the combined CO_2 value [56,62,63].

4.2.10. Korea

The Republic of Korea is the first country in Asia to establish voluntary fuel efficiency targets for the domestic automobile industry and introduce a national mandatory fuel economy car labeling program. In 2005, Korea switched from a voluntary program to a regulatory one [6]. A sample of the fuel economy label in the Republic of Korea is presented in Appendix A. The ratings distinguish different grades, with 1st being the best or highest, and 5th being the lowest grade. The Korean car label is smaller than labels used in other countries. While in other countries car labels are placed on the front wind screen, the Korean car label is placed in the window of the rear door. While in other countries the label is expected to be removed when the sold car leaves the dealership, the Korean car label is meant to remain on the car throughout its useable life-span [52].

4.2.11. New Zealand

The Institution of Professional Engineers New Zealand (IPENZ) has strongly supported the intention of government to convey fuel economy information to vehicle purchasers. In New Zealand, as vehicle purchases are increasingly being initiated through web-based searches, it is recommended that "labeling" also includes compulsory information. Therefore, physical labeling on the vehicle itself will not be sufficient in isolation. It has been noted that government and public are interested in performance specifications. Therefore, it seems appropriate for labeling to encompass global emissions performance (for example, CO_2 emissions), local air quality emissions performance (for example, emissions build) and fuel compatibility (such as fuel specification, including bio-fuels compatibility) [64].

5. Capacity for improvement in vehicle fuel efficiency

The amount of fuel consumed by a motor vehicle over a distance is affected by the efficiency of the vehicle in converting the chemical energy in motor fuel into mechanical energy and transmitting it to the axles to drive the wheels. Only about 15–20% of the energy from the fuel is ultimately transmitted as power to the wheels. Fig. 17 depicts the energy flows and sinks for a conventional gasoline-powered midsize passenger car [65,66].

Since 1975, the fuel economy of the combined car and light truck fleet has moved through several phases [67]:

1. A rapid increase from 1975 through 1981.
2. A slow increase until reaching its peak in 1987.
3. A gradual decline until 2004.
4. An increase beginning in 2005.

There are many opportunities to improve fuel efficiency and economy of motor vehicles. These opportunities comprise making changes to the following [24,29,68]:

- Engine, transmission and vehicle technology.
- Transport fuel mix.

Worldwide research showed that there is significant possibility for improvement in fuel efficiency for vehicle operating on conventional internal combustion engines. These improvements can take place through more extensive implementation of proven fuel saving engine, transmission and vehicle technologies as well as improvement in vehicle design and materials.

The UK Government, released the King Review, this review shows that 30% of fuel savings are achievable for the average new light passenger vehicle in the short term (5–10 years). This conclusion does not rely on downsizing or major fuel shifts, but simply it adopts the selection of the most cost-effective technologies. These reports also conclude that the additional costs of delivering these improvements were moderate, and likely to be fully offset in 3–5 years of vehicle ownership because of lower fuel costs.

Throughout the history of automobile the technology and design improvements have been always directed towards improvement of engine, transmission, vehicle body and accessories for obtaining higher fuel economy. The broad areas of design improvements in different vehicle systems are given below [25,30]:

- Vehicle power requirement
- Engine technology
- Transmission
- Alternative power plants

These technologies, their associate potential fuel efficiency improvement and potential average retail price increases ($) are summarized in Appendix B [29,43,69,70].

5.1. Vehicle power requirement

Vehicle when moving on road has to overcome rolling resistance caused by the vehicle weight, the friction between wheels and road, air drag and the electric power required by a range of vehicle accessories that are necessary as well as those required for comfort. The rolling resistance depends on vehicle weight, friction coefficient between tires and road surface, the tire design and materials and the quality of road surface. The rolling resistance increases with vehicle speed, but weakly. The air drag however, increases in proportion to the square of vehicle speed, and engine power required overcoming air resistance increases in proportion to the cube of vehicle speed. Therefore, reduction in the vehicle weight, air drag and rolling resistance are important factors to reduce the vehicle power demand and thus improving fuel economy [29].

5.1.1. Vehicle weight

Trends in the weight of different categories of passenger vehicles have increased in the last 20 years. For instance, in Europe the average weight of the passenger cars and light duty vehicles increased by nearly 20% from 1000 kg in 1980 to around 1200 kg in 1998. In fact, the increase in vehicles weight was to meet some specific demands of passenger comfort such as electrically actuated windows, seats, mirrors and air conditioning and safety procedures such as seat belt tensioners, air bags, and brake control systems. Improved crash safety measures required stronger vehicle chassis and body structure, and hence increase the vehicle weight. This increase requires more powerful engines. However, by the year 2005 the weight of light duty vehicles in Europe dropped again to 1000 kg due to the establishment of the fuel economy standards [29,71]. Lowering vehicle weight reduces tire rolling resistance, and the energy required to speed up a vehicle to a given speed and thus reduces vehicle fuel consumption. The vehicle weight can be reduced by a combination of lightweight materials substitutions and vehicle redesign. Material substitution involves replacing heavier iron and steel used in vehicles with weight-saving materials like aluminum, high-strength steel (HSS), magnesium, plastics and polymer composites. Of these, aluminum and HSS are more cost-effective at large production volume scales [19]. According to Mitsubishi, a 45% weight reduction in the car roof can be achieved by the use of aluminum-alloy sheet. Since the roof is

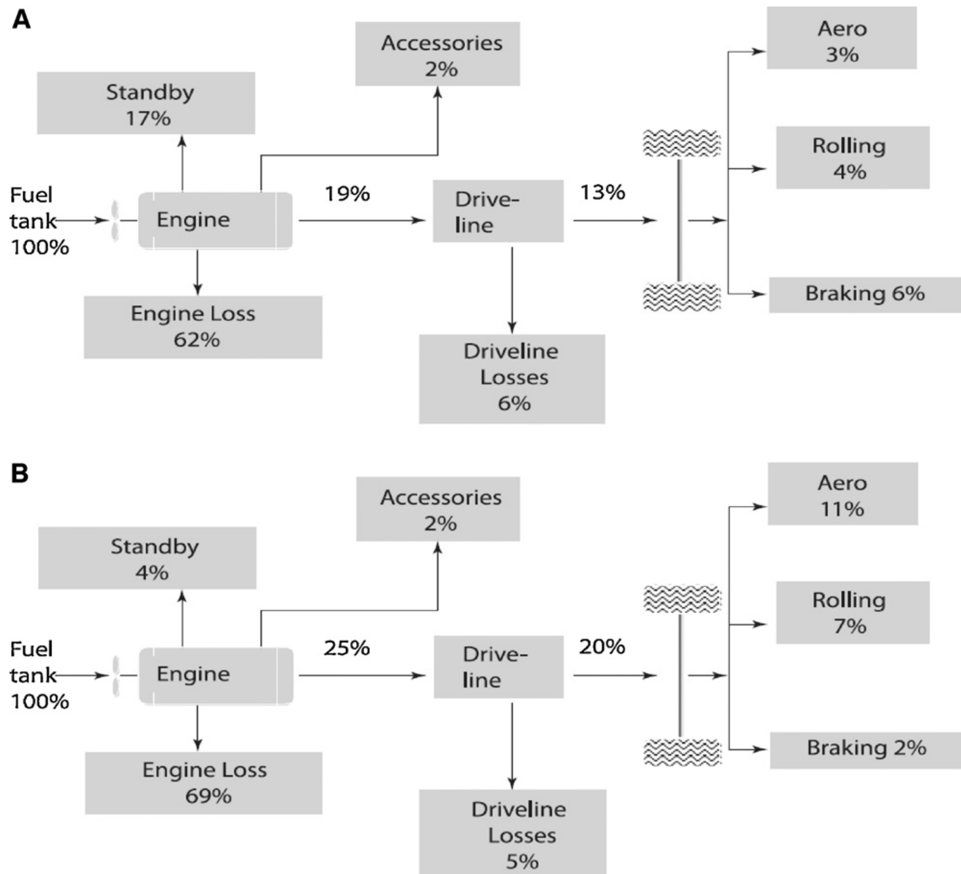

Fig. 17. Energy flows for a late-model midsize passenger car under: (a) urban driving; (b) highway driving [65,66].

the highest-positioned part of the vehicle, a weight reduction in the roof effectively lowers the vehicle's center of gravity and can thus greatly improve the vehicle's handling performance. However, roof's weight reduction may carry a risk of reduced roof strength and increased cabin noise. The aluminum roof model was developed so as to achieve body strength and cabin quietness comparable with those of the current steel-roof model [72].

It is estimated that a reduction of 100 kg in weight of the average European car would reduce fuel consumption by 0.2 l/100 km. For the North American SUVs, a reduction of 2–3 kg (4–7 pounds) in vehicle weight is expected to improve vehicle fuel economy by 0.01 mpg [30,73]. Fig. 18 shows the trends of fuel consumption to weight ratio in different selected countries around the world since 1975 [67,74].

5.1.2. Air drag coefficient

The aerodynamic styling of the body, air flow through passenger compartment and engine compartment, air flow through wheel housing to cool brakes, underbody surface, rear view mirrors, wind shield wipers, antennas and door handles, etc. are all contributors to increase air drag. The resulted air resistance force can be calculated from the following equation:

$$F_w = C_w A \frac{\rho V^2}{2}$$

For the recent modern cars, the air drag coefficient has been reduced to below 0.30 for the passenger cars. This reduction has been achieved through technological advancement in aerodynamic styling of the body and making flow of air smooth over the body exterior, underbody and components [30,75,76]. It is estimated that a reduction of 10% in drag coefficient can decrease fuel consumption by 2–3.5%. Moreover, the reduction in air drag coefficient results in higher fuel economy benefits during highway driving [29,30,71].

5.1.3. Rolling resistance

As has been mentioned earlier, vehicle rolling resistance depends on vehicle weight and the coefficient of friction between tires and road at a given speed. The value of friction coefficient varies with the tire material, tire width and inflation pressure. For instance, the tire friction can be reduced by about 25% if tire pressure is increased by 0.5 bar. However, cares should be taken to the drastic reduction in friction coefficient because it may result in loss of tire grip to road under wet conditions. This condition may raise the safety concerns and loss in driving smoothness. Generally, there are two ways to minimize rolling resistance. One is to drive on properly inflated and aligned tires. The other is to use tires that possess low rolling resistance at proper inflation levels. Reduction in rolling resistance can cause an improvement of 1–1.5% in fuel economy particularly for the larger vehicles like MUVs and SUVs [29,30,65].

5.2. Engine technology

Globally, there are a great number of advanced engine technologies for fuel economy improvement have been developed and put in production. Some of these technologies are common to both the gasoline and diesel engines and while others are specific to the engine combustion type. Some of the most important technologies are [29]:

- Multiple valves.
- Variable valve timing and lift systems.
- Downsizing of the engine by turbocharging/supercharging.

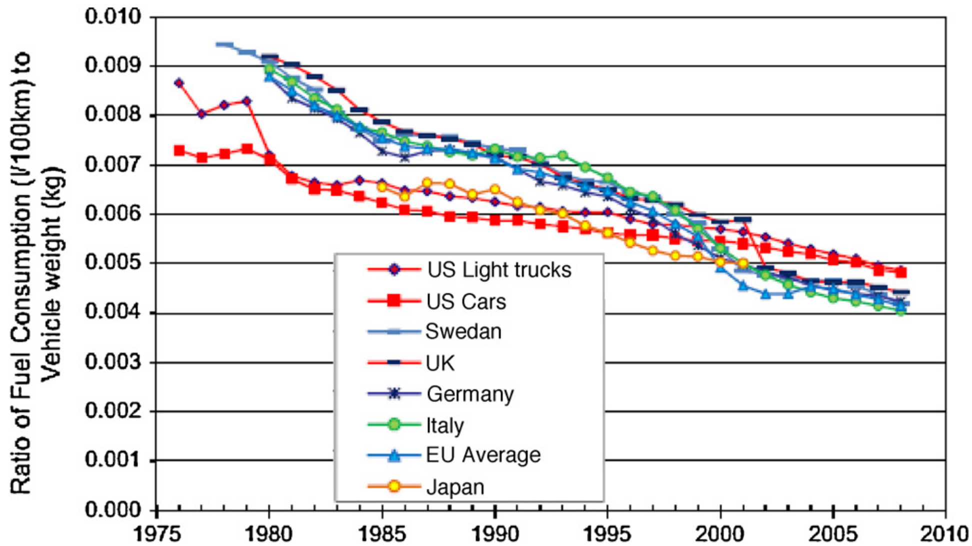

Fig. 18. Fuel consumption to weight ratio for new cars (sales weighted average of diesel and gasoline models) [74].

• Cylinder deactivation.
• Stop–start systems.
• Friction reduction.

In the following discussion, a brief discussion of some of these technologies will be discussed.

5.2.1. *Multiple valves*

Currently, most of internal combustion engines utilize 4 valves per cylinder. In this configuration, the flow area through intake and exhaust valves increases significantly. The double overhead cam shaft for 4 valve operation provides more flexibility to the designer to control valve timings and lift. The 4 valve configuration provides an improvement in volumetric efficiency, better control of mixture motion and locating spark plug centrally in the combustion chamber for gasoline engines and central location of the injector in diesel engines. With 4 valves per cylinder 2–5% fuel economy improvements are possible compared to a 2 valves per cylinder engine. Due to these reasons, 4-valve technology results in about 3–5% improvement in fuel economy [29].

5.2.2. *Variable valve actuation*

This type is also known as variable valve timing (VVT), variable-cam timing and variable valve timing and lift electronic control (VTEC). This type is applicable to the engines with dual overhead camshafts (OVC) and not to those engines that have simply the overhead valves. In internal combustion engines, optimum timing and lift settings are different for high and low engine speeds. Conventional internal combustion engines use fixed timing and lift settings which are a compromise between the optimum for high and low speeds. Variable valve timing (VVT) systems automatically alter timing and lift to the optimum settings for the engine speed. It also reduces pumping work at part loads while retaining good high speed engine performance. For example, early closing of intake valve at part loads and low speeds reduces pumping work compared to late intake valve closure which is beneficial at high engine speeds. Low intake valve lift at idling and low load operation results in smoother engine operation resulting from higher inlet charge velocities creating high turbulence. Idling speed in such engines can be reduced that further lowers the fuel consumption. Variable valve timing and lift can be employed for internal exhaust gas recirculation for NO_x emission control and it works better than the external exhaust gas recirculation by improving fuel vaporization and homogeneous mixture preparation.

This technology was first applied by Alfa Romeo in 1983. In 1989, Honda introduced VTEC and around the same period Toyota produced VVTi technology. Afterward, most of other automobile manufacturers applied this technology. It is estimated that, this technology can improve the fuel economy of vehicles for 3–5%. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $1300 [29,66,67].

5.2.3. *Engine downsizing*

Using an engine with smaller swept volume is another way to improve fuel economy. Smaller engine has lower friction losses and during city driving it would operate closer to best efficiency point resulting in improvement in fuel economy. At high speed driving, the engine power is boosted by turbocharging and supercharging. Turbochargers and superchargers are fans that force compressed air into an engine's cylinders. A turbocharger fan is powered by exhaust from the engine, while a supercharger fan is powered by the engine itself. The conventional gasoline engine is not very much suited for turbocharging due to increased rate of knocking problems. However, the GDI engines are better suited for turbocharging. In future, downsized turbo-GDI engines may be introduced to further improve the fuel of the GDI engines. It is believed that downsizing GDI engine with turbo/supercharging can achieve 10–15% fuel saving [24,29].

For diesel engines, the use of turbocharging with inter-cooling cause higher power output compared to the same engine size. The advantage of turbocharging is that it provides the designer more flexibility in adjustment of engine parameters like injection timing, excess air that give better trade-off between emission control and higher fuel economy. Turbocharging with intercooling has resulted in improving fuel economy between 3 and 7.5%. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $1900 [29,66].

5.2.4. *Cylinder deactivation*

Cars during city driving use only a small tiny proportion of engine power. Cylinder deactivation which is also called *multiple displacements, displacement on demand (DOD)*, and *variable cylinder management* can merely deactivate some of the engine's cylinders when they are not needed. This technology is emerging but is applicable only to the 6 and 8 cylinder engines which turn them into 3 and 4 cylinder engines. This technology is not used

on 4 cylinders engines since it would cause a noticeable decrease in engine smoothness. The average fuel economy improvements is about 7.5% are obtained. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $1900 [29,66,67].

5.2.5. Stop–start systems

In the city operation vehicles stop frequently due to traffic jam or traffic lights. These repeated stops will result in considerable waste of fuel consumption. Integrated starter–alternator is a system that automatically shut down the engine when the vehicle comes to a stop and restarts it instantaneously when the accelerator is pressed. This system is used by Volkswagen, Citroen and BMW. For successful implementation of stop–start system the health of battery is to be monitored so that when it is in poor condition the system bypasses the engine stop–start mode. These technologies are more easily adopted applied with the use of starter–generator systems like BAS (Belt driven Alternator-Starter) or integrated starter–generator machines. Other more sophisticated systems termed as 'SISS (Smart Idle Stop System)' have been developed that make the engine to at mid-piston stroke so that minimum restarting torque is required. This system is expected to boost fuel economy by 8% especially for the vehicles that use a lot of electric driven accessories. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $2000 [29,66].

5.2.6. Friction reduction

Reduction in engine friction can be gained by the use of lower viscosity oils and improving the designs of rings and other rubbing components. For instance, use of low viscosity engine oils such as 10W-30 oils or 10W-40 with anti-wear additives instead of 20W-40 in severe climatic conditions will result in better fuel economy. The improvements in oil control rings design can reduce oil consumption in combustion chamber. It will result in lesser engine deposits in combustion chamber and longer life of catalytic converters, which also would be reflected in better fuel economy over a longer period of vehicle usage. It has been estimated that reducing friction has the potential to improve fuel economy 2–4% [29].

5.3. Power transmission train

The fuel efficiency of an engine can be improved when it operates at low engine speed and at high loads. For instance, if a vehicle has been designed for a 5 gear transmission and it is operated in 4th gear at constant speed of 100 km/h the specific fuel consumption of the engine may typically increase by nearly 15% as the engine would be operating at higher engine speed and lower torque. Research suggested that availability of more gears is likely to make the engine operating close to the best efficiency point. Continuously variable transmission (CVT) provides best means to implement this strategy. A larger number of gears 5–6 in comparison to 4 forward gear ratios also results in better fuel economy [29]. CVTs use a pair of variable-diameter pulleys connected by a belt or chain that can produce an infinite number of engine/wheel speed ratios. Advantages of this system include [66]:

- Seamless acceleration without the jerk or jolt from changing gears
- No frequent downshifting or "gear hunting" on hills
- Better fuel efficiency

This system is expected to boost fuel economy by 6%. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $1500.

Use of front wheel drive (FWD) eliminates propeller shaft, rear differential and drive axles. In FWD vehicles, engine is mounted transverse reducing length of engine compartment and for the same passenger compartment length, the vehicle length is reduced. Vehicle weight is also reduced. This is now common for the smaller and compact cars. The FWD vehicles are also better suited for the use of CVT. Elimination of hydraulic torque converter improves fuel economy for around 2–3%. With hydraulic torque converter the engine idling speed is to be kept at higher levels compared to manual transmission increasing vehicle fuel consumption [29,33,77].

Automated manual transmissions (AMT) combine the best features of manual and automatic transmissions. Manual transmissions are lighter than conventional automatic transmissions and suffer fewer energy losses. However, most drivers prefer the convenience of an automatic. AMT operates similarly to a manual transmission except that it does not require clutch actuation or shifting by the driver. Automatic shifting is controlled electronically (shift-by-wire) and performed by a hydraulic system or electric motor. In addition, technologies can be employed to make the shifting process smoother than conventional manual transmissions. This system is expected to boost fuel economy by 7%. Assuming an average vehicle lifetime of 185,000 miles, a fuel price of $2.87, and an average fuel economy of 21 MPG, fuel cost savings over vehicle life time are estimated $1800 [66].

5.4. Alternative power plants

5.4.1. Hybrid electric vehicles

The greater use of hybrid vehicle technologies can offer significant emission reductions of 25–30% for mild hybrids, and 25–50% for full hybrids, and potentially greater than 50% for 'plug-in' hybrids. These technologies are expected to become much more widespread in the medium term (10–20 years).

Mitsubishi, General Motors Toyota and Nissan have all recently announced that they will introduce plug in hybrid/electric models from 2009 to 2010 into the international market [24].

Hybrid electric vehicles (HEV) employ two propulsion systems; an IC engine and a battery powered electric motor. Presently, two types of HEV considered are [19,29]:

(a) Plug-in hybrids (PHEV): during the city, vehicle operation involves a large fraction of idling, stop, start and low load operation. This makes efficiency of the internal combustion engine very low. The plug-in hybrids insulate the engine from operation in city and thus improve overall fuel economy of vehicle. These HEVs operate on storage batteries. The batteries have a limited range of operation sufficient for a single day during city driving. The batteries are recharged by plugging-in them to the main household electricity supply system. However, during highways conditions the batteries are discharged and the vehicle is powered by the internal combustion engine. Currently, PHEV consumes 72% less liquid fuels than the conventional car.
(b) Full hybrids: in this system, the internal combustion engine is cut-off from the wheels. The propulsion batteries are constantly charged by the internal combustion engine. Vehicle propulsion in series hybrids is entirely from the battery powered motor. In parallel hybrids engine provides traction simultaneously when power demands are higher like during acceleration mode. Currently, HEV consumes 30% less liquid fuels than the conventional gasoline car. This is due to the following factors [19,30,78]:
    (i) IC engine in HEV is operated mostly at constant load and speed close to point at which best efficiency is obtained.

(ii) Initial movement of vehicle is by electric motor powered by batteries.
(iii) A smaller engine is used and 'downsizing' concept is put to practice.
(iv) Partial recovery of braking energy is possible.
(v) It is possible to design a very efficient IC engine using new technologies like Atkinson cycle as the engine operates at nearly constant load and speed that further boosts the engine efficiency at very low emission levels.

Toyota Prius HEV was adjudged by the Automotive Engineering International as the best engineered vehicle of the year 2004. The first generation Toyota Prius introduced in 1998, had 1.5 l, 43 kW gasoline engines, which was upgraded to 53 kW in 2001. The second generation Toyota Prius was put into production in 2004. It uses a 4-cylinder gasoline engine with DOHC, 4-valve/cylinder and VVTi. The engine operates on Atkinson cycle via late inlet valve closure (72–115° ABDC). The 2001 model gave 48 mpg (20.4 km/l) on CAFE test cycle. The second generation Toyota Prius weighs 1250 kg and gives 55 mpg (23.4 km/l) on combined US city and highway fuel economy test cycle compared to the CAFE standard of 27.5 mpg. Honda has Insight and Civic hybrid car models [78].

A number of manufacturers like Toyota, Honda, Ford and Mercedes have introduced hybrid SUVs. These SUVs are for the customers who normally preferred high power SUVs using V-6 and V-8 engines. A 2004, hybrid SUV using gasoline engine gave 27.6 mpg and a diesel engine powered hybrid SUV gave 33 mpg on CAFE test cycle [75]. Chevrolet Tahoe, GM hybrid SUV with 8 passenger capacity, 2810 kg curb weight achieves 50% better city cycle and 30% better combined cycle fuel economy compared to its gasoline engine counterpart [76].

6. Conclusion

Globally, the transportation sector is the second largest energy consuming sector after the industrial sector and accounts for 30% of the world's total delivered energy. It is believed that this sector is currently responsible for nearly 60% of world oil demand. Road vehicles dominate global oil consumption and are one of the fastest growing energy. It represents 81% of transportation energy demand.

There are many measures to improving fuel economy and reduce CO_2 emission of vehicles. In this paper, three measures have been reviewed; passenger vehicle fuel economy and greenhouse gas emission standards, fuel economy labels and improvement in vehicle fuel efficiency by advanced technologies.

Fuel economy and greenhouse gas emission standards have proven to be one of the most effective tools in controlling oil demand and greenhouse gas (GHG) emissions. Globally, there are nine major regions around the world that have implemented or proposed various fuel economy and greenhouse gas (GHG) emission standards. These regions include: USA, California, European Union, Canada, Japan, China, Taiwan, South Korea and Australia.

Labeling could play an important role in consumers' vehicle purchasing decisions between similar vehicles that have different fuel efficiency ratings. Labeling accompanied by standards of an appropriate type and level of stringency may yield synergistic results.

In this review, several examples of fuel economy labels around the world have been reviewed such as in USA, United Kingdom, Canada, China and Australia.

The technological advancement could play an important role to improve fuel efficiency of motor vehicles. Throughout the history of automobile the technology and design improvements have been always directed towards improvement of engine, transmission, vehicle body and accessories for obtaining higher fuel economy. In this review, the following possibilities in vehicle design have been reviewed: vehicle power requirement, engine technology, transmission and alternative power plants.

In conclusion, it can be summarized that fuel economy standards, labels and technologies offer a huge potential of energy saving that can be achieved in this sector and thus the authors promoted adopting these measures in the transportation sector.

Acknowledgment

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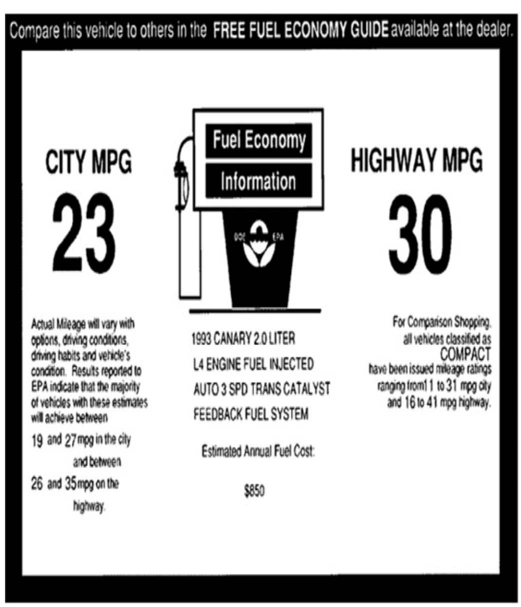
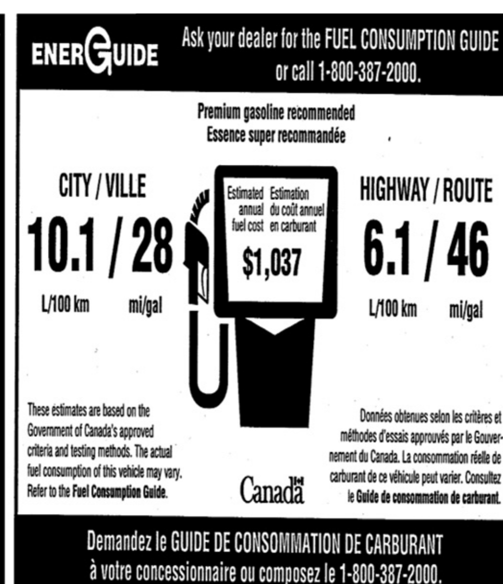
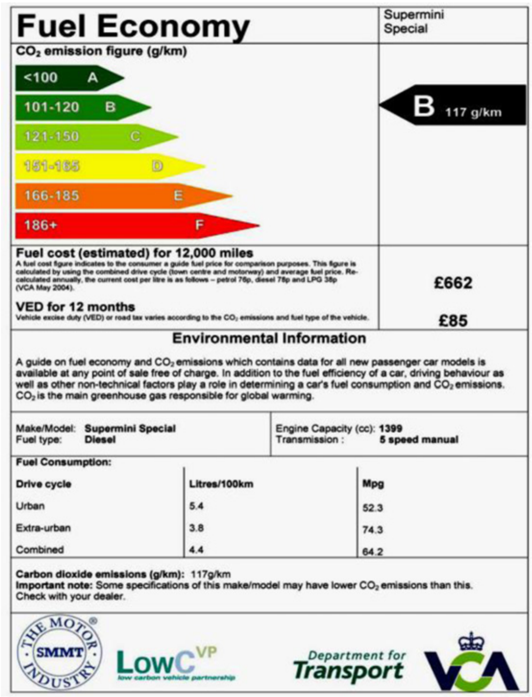
Appendix A.



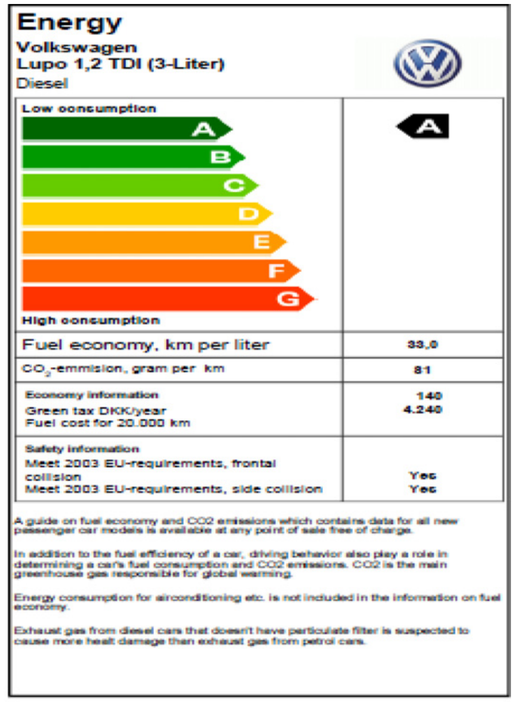
United States



Canada



United Kingdom



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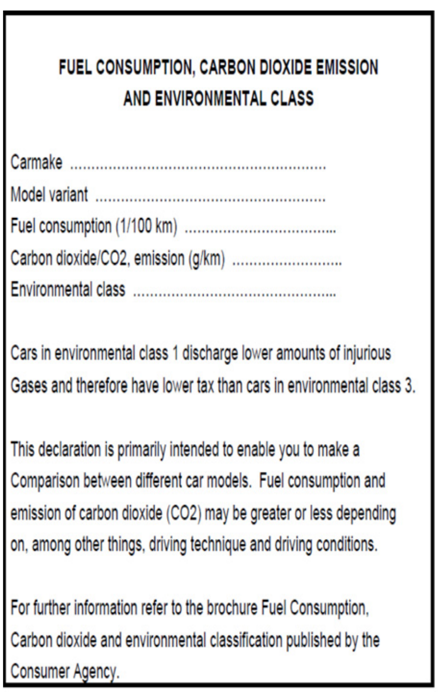
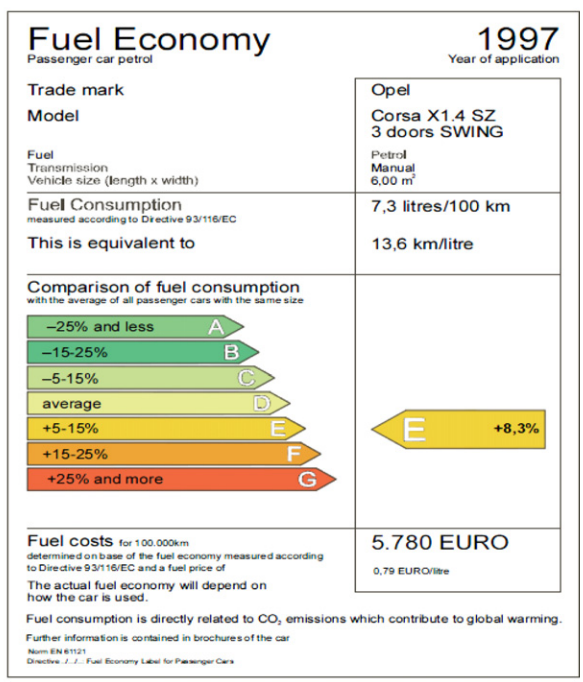
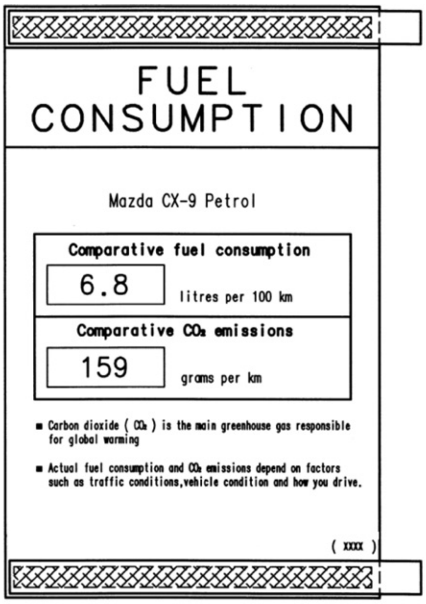


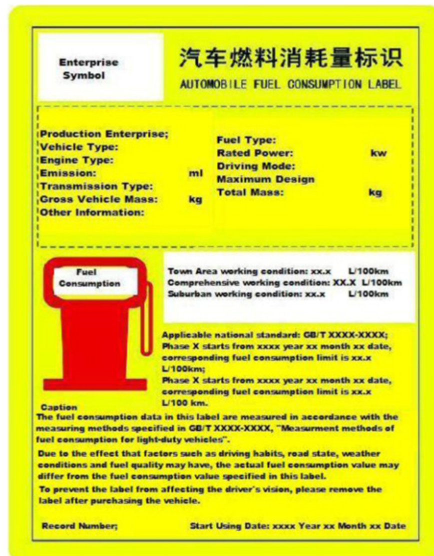
Sweden



European Union

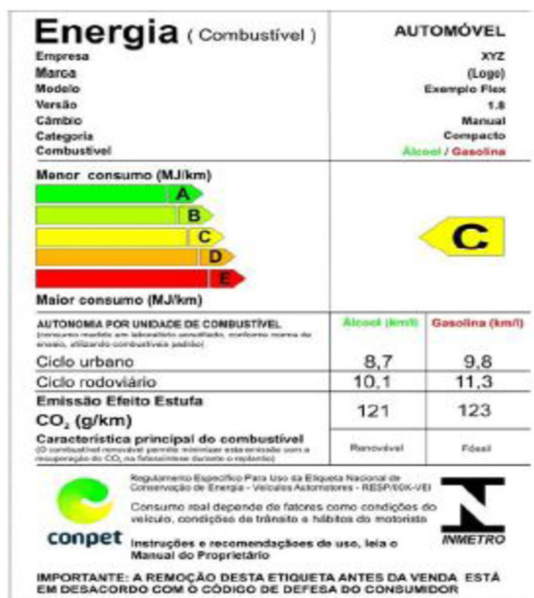


South Africa

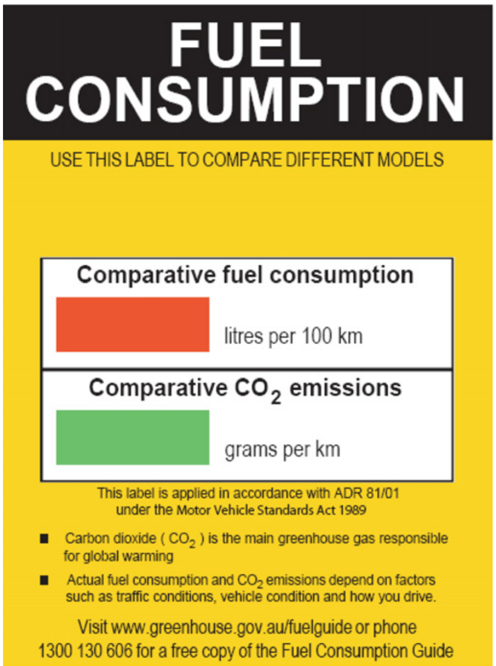


China

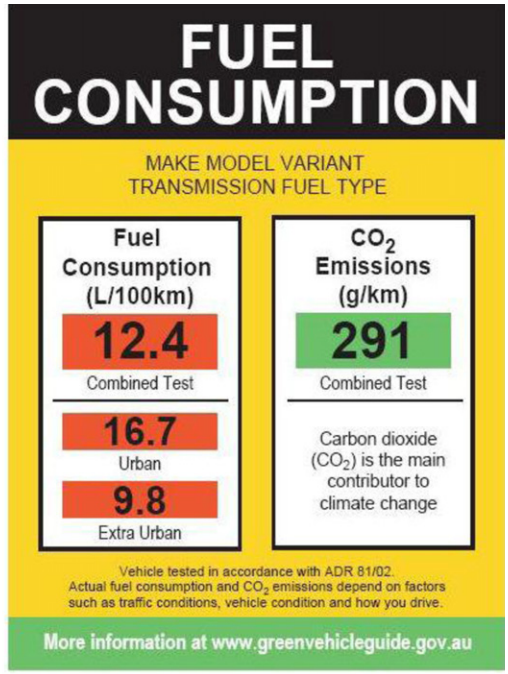
California



Brazil



Old Label

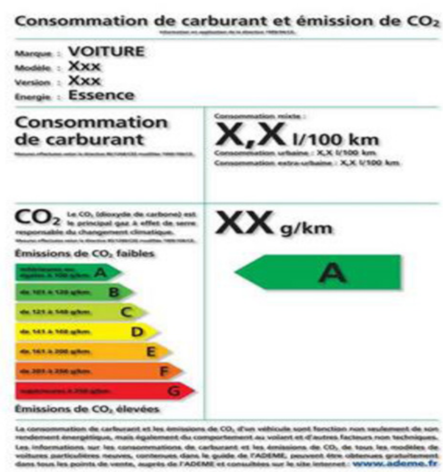


New Label

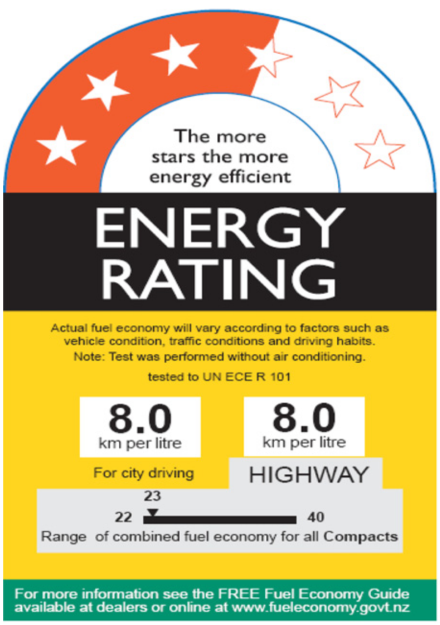
Australia

Japan

Republic of Korea

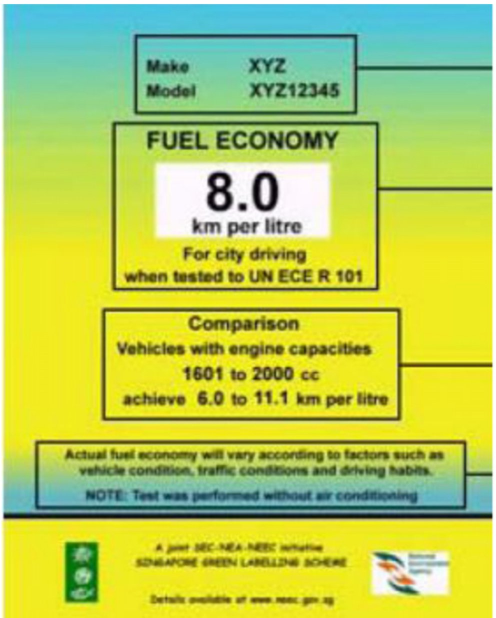


France

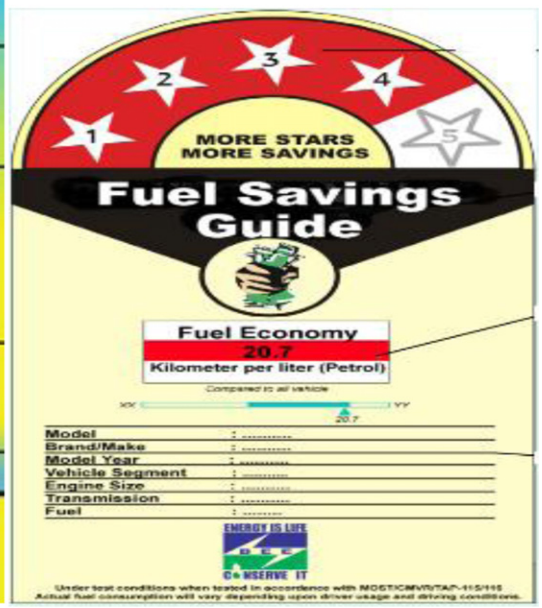


New Zealand

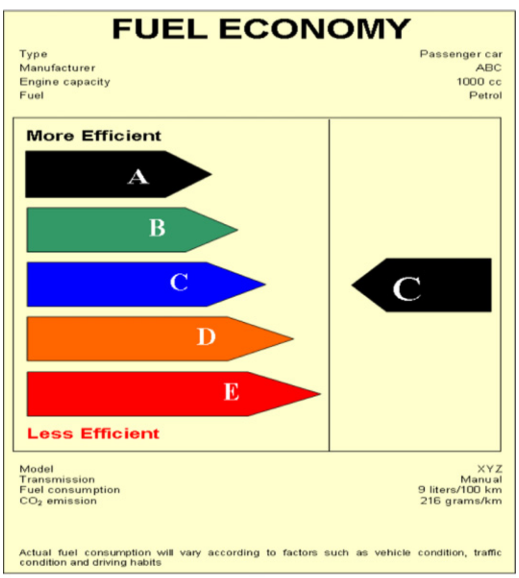
Chile



Singapore



India



Pakistan

Appendix B.

Technology	FE improvement (%)		Potential average retail price increases ($)
	Low	High	
Production-intent engine technologies			
Engine friction reduction	1.0	5.0	35–140
Low friction lubricants	1.0	1.0	8–11
Multi-valves, overhead camshaft	2.0	5.0	105–140
Variable valve timing (4, 6, 8-cylinder engines)	2.0	3.0	35–140
Variable valve lift and timing	1.0	2.0	70–210
Cylinder deactivation (6 and 8-cylinder engines only)	3.0	6.0	112–252
Engine accessory improvement	1.0	2.0	84–112
Engine supercharging and downsizing	5.0	7.0	350–560
Emerging engine technology			
Intake valve throttling	3.0	6.0	210–420
Camless valve actuation	5.0	10.0	280–560
Variable compression ratio	2.0	6.0	210–490
Production-intent transmission technology			
5-Speed automatic transmission	2.0	3.0	70–154
Continuously variable transmission (CVT)	4.0	8.0	140–350
Automatic transmission with aggressive shift logic	1.0	3.0	0–70
6-Speed automatic transmission (v/s 5-speed A/T)	1.0	2.0	140–280
Emerging transmission technology			
Automatic shift manual transmission	3.0	5.0	70–280
Advanced continuously variable transmission (CVT)	0.0	2.0	350–840
Production-intent vehicle technology			
Air-drag reduction	1.0	2.0	0–140
Improve rolling resistance	1.0	1.5	14–56
Emerging vehicle technology			
42-Volt electrical system	1.0	2.0	70–280
Integrated starter/generator	4.0	7.0	210–350
Electric power steering	1.5	2.5	105–150
Vehicle weight reduction (5%)	3.0	4.0	210–350

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